An Investigation of Extreme Ultra-violet Spectra, with a Vacuum-grating Spectrograph.

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[Plate 3.]

I. *Introduction.*

It has been pointed out in another communication* that some considerations connected with the investigation of ionisation potentials for the different elements made it necessary to work out their series spectra as far down in the ultra-violet as it was practicable to go. The results of some studies with quartz and fluorite spectrographs have already been published, and in the present communication an account is given of some preliminary observations made with a vacuum-grating spectrograph. This work, as well as that in other directions, has had to be discontinued for the present through the exigencies of the war situation, and is therefore incomplete. The results obtained so far, however, are interesting in that they show that it is quite feasible to investigate, with comparative ease, spectra including wave-lengths as short as $\lambda = 584$ Å.U.

II. *The Vacuum-grating Spectrograph.*

The vacuum-grating spectrograph was designed by and obtained from the Adam Hilger Company. A sectional plan and sectional elevation of this instrument is shown in fig. 1. Sketches of the grating mounting are shown in fig. 2, and others of the slits, slit taps, auto-collimating eyepiece and film carrying taps are sketched in fig. 3.

The spectrograph was formed of a brass tube (A), 115 cm. long, 15 cm. in diameter, and 3·5 mm. thick. At one end there was a cover (B) ground in and soldered, and at the other a casting containing the slit and film holder. The slits (K), of which there were two 5·5 cm. apart, were mounted in a recess in the casting, and kept air-tight when desired by a window. Each slit was provided with a tap (O), to enable exposures to be made. The film (H) was carried in the main tap (G). The tap body had an aperture (M) to enable the film carrier to be loaded, and an exhaust tube (L) to exhaust the film carrier before the exposure was made. This ingenious arrangement was intended to make it possible to introduce a plate without losing the vacuum in the main tube.

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* McLennan and Young, see next paper.

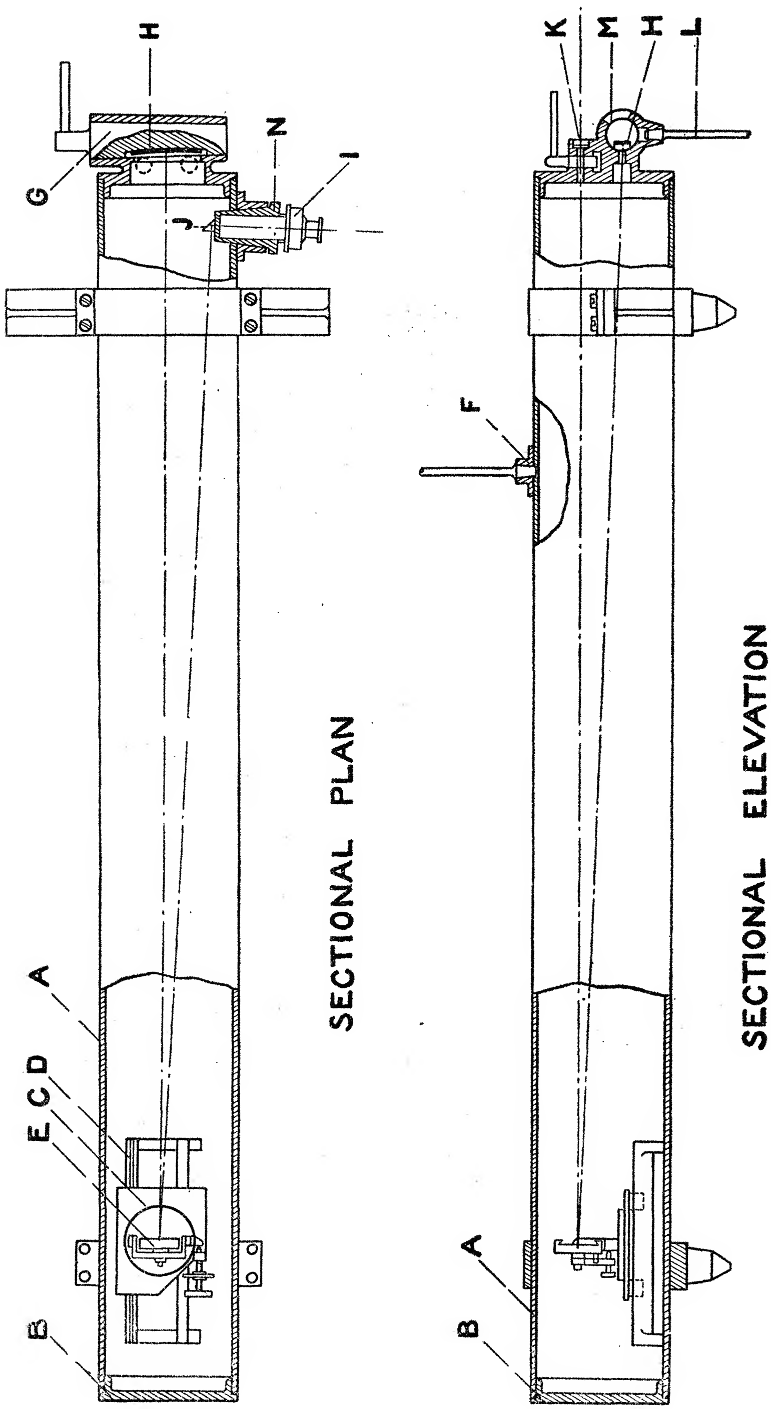
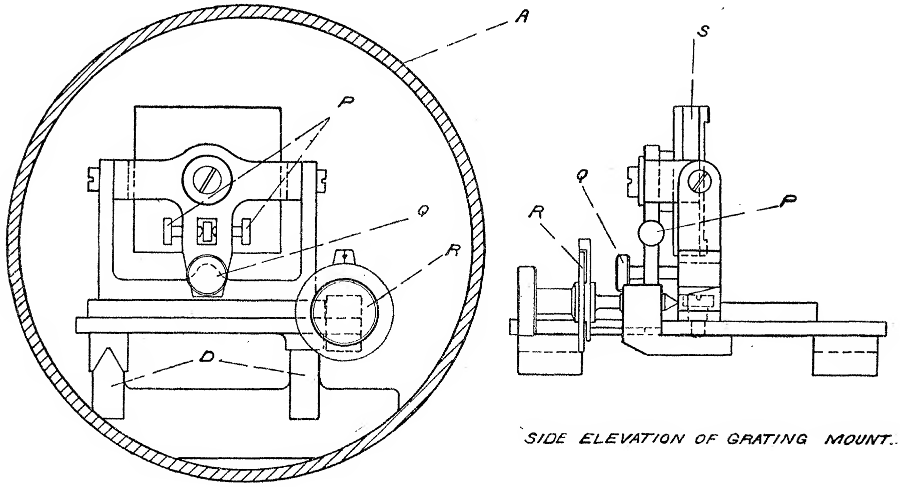


Fig. 1.

The various parts with their designating letters are as follows:—

A.	Tinned brass tube.
B.	Ground end plate.
C.	Grating carriage.
D.	Rails for carriage.
E.	Ruled diffraction grating; 20,000 lines per inch, 120 cm. radius.
F.	Tube with ground fitting for exhaust.
G.	Large ground tap containing film carrier.
H.	Photographic film, Schumann sensitised.
I.	Auto-collimating eye-piece.
J.	Glass right-angled prism.
K.	Slit.
L.	Exhaust tube for film carrier.
M.	Aperture for loading film carrier.
N.	Ground fitting for eye-piece, replaced by ground plug in working.
O.	Ground taps for exposing through slit.
Q.	Screw for adjusting vertical inclination of grating.
R.	Micrometer screw for setting orientation of grating.
S.	Mount for diffraction grating.

At the slit and film end of the tube on one side there was a mount for an auto-collimating eye-piece (I) and prism (J) mounted in a taper plug (N). When not in use, the plug (N) with eye-piece and prism were withdrawn complete and replaced by a solid plug.



SIDE ELEVATION OF GRATING MOUNT.

SECTION OF SPECTROGRAPH LOOKING TOWARDS GRATING MOUNT

Fig. 2.

At the other end of the tube were rails (D) on which slid a carriage (C) carrying the grating mount (S). The length of rails was sufficient to allow about 10 cm. travel for the carriage. The ruled grating No. 106 was 2·5 cm. wide and 1·9 cm. high. Its radius of curvature was 120 cm., and its ruling consisted of 20,000 lines to the inch. The mount was provided with adjusting screws (P) for setting the lines of the grating parallel to the slit, an adjusting screw (Q) for vertical inclination of the grating, and a micrometer screw for setting orientation of the grating. The tilt of the grating and also of the film was 3° 13′. The main exhaust pipe (F) was situated near the

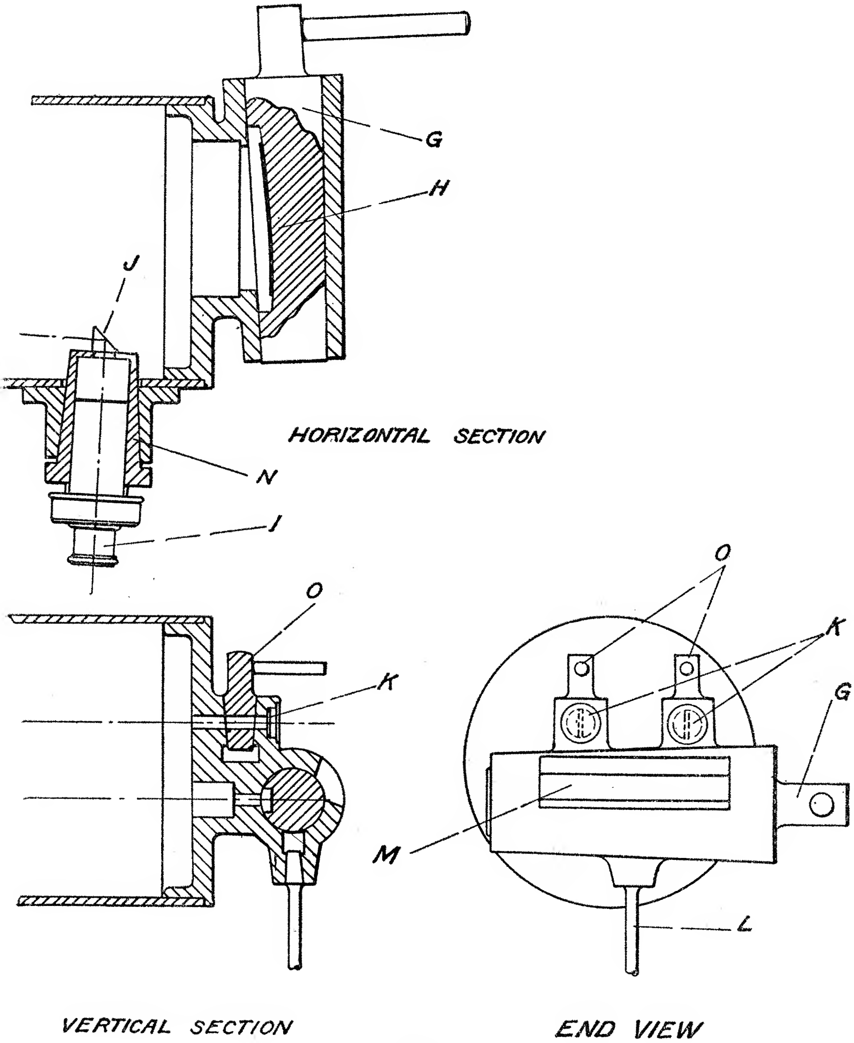


Fig. 3.

slit and film end of the tube. The volume to be exhausted was about 23·5 litres.

The inside of the main tube and all brass work in its interior were tinned; in the case of ground fittings, such as the taps (G) and (O), the grinding was done after tinning. It was found exceedingly difficult to secure complete absence of porosity by tinning, and in the end this was accomplished by painting the whole of the exterior of the main tube with a thin layer of heated Chatterton's compound. In the course of the work, it was found to be an advantage to paint the whole of the interior surface of the large tube a dull black to prevent reflections, and a number of diaphragms were placed at equal distances throughout its length for the same purpose.

A cylinder, made of brass tubing, 30 cm. long and 10 cm. in diameter, and not shown in the drawings, was connected to the main spectrograph tube by means of a short tube of large diameter. Through an opening in the end of this smaller cylinder a pan containing a thin layer of P_2O_5 and covered with glass wool could be inserted or withdrawn as desired. To secure the best results, it was found necessary to remove all water vapour from the interior of the apparatus. Before making exposures with the arrangement described, considerable quantities of phosphorus pentoxide could be used, and this removed the vapour very rapidly when each exhaustion was made. The opening through which the tray was inserted was closed with a brass plate and made air-tight with the Chatterton compound.

The photographic plates used were of the Schumann type, manufactured by the Adam Hilger Company. They were cut as desired from larger plates, and were about 5 mm. in width and 8 cm. in length. About 700 Å.U. was the range which it was possible to investigate with one slit without shifting the grating. The plate-holder was of such a construction that the thin plates when inserted in the holder were bent to an arc of the circle which included the face of the grating.

In making the exhaustions, two Trimount oil pumps in series, run at 250 R.P.M. were used. To test the character of the vacuum obtained from time to time, a short glass vacuum tube was sealed by a side tube into an opening made in the side of the spectrograph main tube. A discharge from a small induction coil was sent at intervals through the vacuum tube, and the appearance of the discharge gave an indication of the pressure within the apparatus.

Connection from the spectrograph to the pumps was made through a lead pipe, of about 1 inch diameter, provided with a $\frac{7}{8}$-inch Jenkins' disc steam-valve. This steam-valve, which was provided with an oil seal, as well as the usual stuffing-box arrangement around the stem, worked very satisfactorily.

In practice it was found impossible to keep the ground joint made by the tap G with its matrix perfectly airtight at every point without coating all exposed parts of the joint with wax. In turning the tap to expose a plate, this wax coating was always broken, with the result that leaks occurred. After spending considerable time trying to rectify this defect, the best results were finally obtained by abandoning the idea of exhausting the plate-holder space in the tap G preliminary to turning the latter so as to expose the plate.

The tap G as originally provided with the apparatus, was replaced by a second one, shown in fig. 4. This large tap carried the plate-holder as the original one did, and instead of the plate-holder being inserted in a recess in the side of the tap, as formerly, the tap was slotted out to one end, as shown at "A" in fig. 4. This allowed the plate-holder, mounted on a thin brass strip, to be inserted from the end " A." When the plate was inserted, the opening was covered with a small brass disc, which was sealed about its edge with wax. With this arrangement the tap always had its plate-holding recess facing the grating and ready for an exposure. The exposed parts of the tap joint were permanently covered with a wax coating, to secure airtightness.

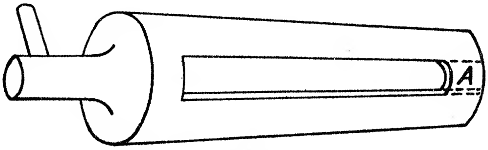


FIG. 4.

The use of the special tap necessitated the re-exhausting of the whole apparatus each time an exposure was made. The Trimount pumps, however, were very rapid and efficient in action, and it was found comparatively easy to reach with half an hour's continuous running a pressure low enough for the induction coil discharge to give green fluorescence in the pressure-testing vacuum tube.

III. *Theory of the Concave Grating.*

With a concave grating all spectra are focussed upon a circle whose diameter is the radius of curvature of the grating. As stated above, the plate of the spectrograph was bent to the arc of such a circle.

In fig. 5 let SPC be a section of the plate; OO′ a section of the grating, with the normal CA; AB the distance between two lines on the grating, or the grating constant; S the source of light, and P a line of wave-length λ, and of the first order.

Since the total length of the plate was only 8 cm. it is clear that P would lie between S and C.

$$SA = SB', \qquad PA = PB'',$$

$$SB - SA = B'B = AB \sin\phi, \qquad PB - PA = BB'' = AB \sin\theta.$$

Total difference of path is $B'B + BB'' = AB(\sin\phi + \sin\theta)$.

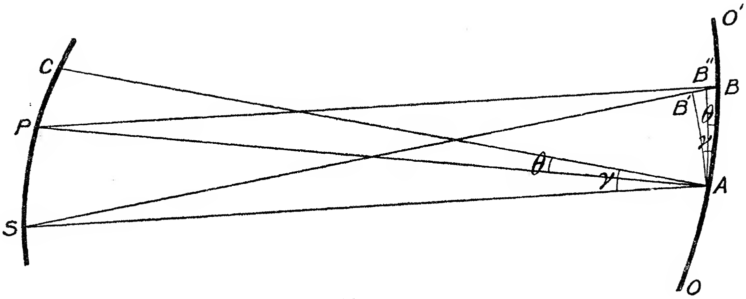


Fig. 5.

Now let "D" be the distance of the line "P" from "S" measured along the plate and let "R" be the distance from grating to the plate.

$$D = R(\phi - \theta) \qquad \text{or} \qquad \theta = \phi - D/R.$$

Therefore $\lambda = AB\{\sin\phi + \sin(\phi - D/R)\}$ expanding the last term we get

$$\sin(\phi - D/R) = \sin\phi \cos D/R - \cos\phi \sin D/R.$$

Now $\cos D/R$ is very nearly equal to unity since "D" is always small compared with "R" and also $\sin D/R$ may be taken as D/R.

Then $$\lambda = AB(2\sin\phi - \cos\phi \,.\, D/R).$$

If now ϕ be taken as constant, *i.e.*, if the grating is kept fixed, we have a straight line curve between λ and "D."

Its slope is $$-\frac{R}{AB\cos\phi}.$$

If the grating be turned to bring an unknown region upon the plate, the slope of the calibration curve is altered, so that the curve is not a continuous straight line. We have therefore a new slope to the curve every time the grating is turned.

Now if after the grating is turned two lines of known wave-length appear on the plate, then we have

$$\lambda_1 = a(2\sin\phi - \cos\phi \,.\, D_1/R), \qquad \lambda_2 = a(2\sin\phi - \cos\phi \,.\, D_2/R),$$

where $a = AB$ above.

Subtracting

$$\frac{\lambda_1 - \lambda_2}{a} = \frac{D_2 - D_1}{R}\cos\phi \qquad \text{or} \qquad \cos\phi = \frac{R}{a}\frac{\lambda_1 - \lambda_2}{D_2 - D_1}.$$

Now the slope of the line was shown to be

$$\frac{-R}{a\cos\phi} \quad i.e. \quad \frac{D_1-D_2}{\lambda_1-\lambda_2},$$

so that one does not need to know anything more than the distance between the two lines and the values of their wave-lengths to plot a calibration curve for the plate for a given setting.

IV. *Method of Determining Wave-lengths.*

The method used to find the wave-length of the lines observed was as follows:—The zinc spark line $\lambda = 2026$ Å.U. was obtained on a plate, and its distance from the short wave-length end of the plate (which always occupied the same position in its holder) measured. A mercury arc spectrum plate was then taken and the distance of the line $\lambda = 1849$ Å.U. found from the end of the plate. Thus the distance between the lines $\lambda = 2026$ Å.U. and $\lambda = 1849$ Å.U. was found. A large sheet of graph paper having one space for each Å.U. and one for each mm. dispersion was procured. The line $\lambda = 2026$ Å.U. was given zero dispersion, and the line $\lambda = 1849$ Å.U. gave a second point. A straight line was drawn through these two points.

This graph was used to obtain the wave-lengths of all lines obtained with this setting of the grating. The two carbon lines $\lambda = 1933$ Å.U. and $\lambda = 1348$ Å.U. were measured in this way. Then the grating was turned and another carbon plate taken which contained these two lines among others. The line $\lambda = 1933$ Å.U. was given zero dispersion, and the dispersion of $\lambda = 1348$ Å.U. measured on this plate. A new straight line graph was obtained having a slightly different slope from the last. Again the grating was turned, and this time the lines $\lambda = 1477$ Å.U. and $\lambda = 1348$ Å.U. were used to get the new graph. Finally, for the last change of the grating the lines $\lambda = 1200$ Å.U. and $\lambda = 1004$ Å.U. were used. This method, it is realised, had some defects, but it is probable that it enabled us to measure wave-lengths to within one Ångstrom unit.

V. *Summary of previous Work in the Extreme Ultra-violet Region.*

The first successful measurements of wave-lengths in the Schumann region were those so brilliantly carried out by Prof. Lyman,* with a concave reflection grating at Harvard. The vacuum grating spectroscope used consisted roughly of the spectroscope itself, and an air-tight case or container. The grating was fixed in one end of the brass tube constituting the spectroscope upon an adjustable mounting. In the other end was a draw-tube carrying the slits and plate holder. The latter was designed to take a number of exposures successively by means of a novel magnetic arrangement which shifted the plate while the vacuum was still maintained. The grating had a radius of 97 cm., and 15,028 lines to the inch. It was ruled with the object of throwing as much energy as possible into one order. The spectra chiefly studied were those of hydrogen and helium, and the sources were end-on discharge tubes.

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* Lyman, "Preliminary Measurement of Short Wave-lengths Discovered by Schumann," 'Nature,' vol. 69, p. 465 (March 17, 1904).

The tubes were separated from the spectroscope by a fluorite window until the limit of the fluorite was reached when the window was discarded and the gas placed in both the tube and the spectroscope. The spark spectra of some metals were investigated by causing a spark to pass between electrodes of the metal in an atmosphere of hydrogen.* These spectra were not carried beyond the limit of the fluorite window because it was found that a rare atmosphere of hydrogen gave nothing but hydrogen lines, while a dense atmosphere in the whole length of the spectroscope was not transparent to the radiations. The possibilities of the spectrum of hydrogen given with the discharge tube reached a limit near 900 Å.U.,† and helium was substituted.‡ It is fortunate that both these gases, which according to the Bohr theory have a series of lines in the Schumann region, should be transparent to these extremely short waves.

Prof. Lyman found more than 300 lines in hydrogen, the shortest being about 900 Å.U. The first three lines of the series predicted by Ritz as an analogue to Balmer's series, namely, $\lambda = 1216$ Å.U., $\lambda = 1026$ Å.U., and $\lambda = 972$ Å.U. were found. The use of helium in an ordinary discharge tube gave no lines not already found in hydrogen, but when a strong disruptive discharge was employed new lines appeared, the shortest being about 600 Å.U. This appears to confirm the Bohr theory, that the helium atom, having lost but one electron, should upon its return show a spectrum very similar to hydrogen, but that when both electrons are returning it should show a spectrum of its own.

Besides this work in hydrogen the arc spectra of nitrogen, carbon monoxide, argon, calcium, strontium, and mercury were extended to about $\lambda = 1400$ Å.U., while the spark spectra of mercury and aluminium were carried to $\lambda = 1250$ Å.U.

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* 'Spectroscopy of Extreme Ultra-violet,' Lyman.

† "An Extension of Spectrum in Extreme Ultra-violet," 'Phys. Rev.,' vol. 3, Series 2 (1915).

‡ "Extension of the Spectrum beyond the Schumann Region," Lyman, 'Astrophys. Journ.,' vol. 42, No. 2 (March, 1916).

Besides the work of Prof. Lyman, that of Handke[*] and Wolff must be mentioned. The former worked with spark spectra and succeeded in charting zinc, copper, tin, silver, and gold to, approximately $\lambda = 1600$ Å.U., while the latter carried the arc spectra of mercury, cadmium, and zinc to about $\lambda = 1400$ Å.U. The opacity of fluorite, of course, limited both these experiments.

In a recent note on "The Limit of the Spectrum in the Ultra-violet,"[†] Prof. Lyman describes some later experiments. In these he used a concave grating of 50 cm. radius in place of the 100 cm. one previously employed. The design of the quartz discharge tube was altered so that the end of the capillary could be brought near to the slit. The potential difference of the transformer was also increased. Using helium at 1–2 mm. pressure, he extended the spectrum of the gas from 600 Å.U. to 510 Å.U. A trace of a line was also found on his plates at 450 Å.U., but it was far too faint, in his view, to afford trustworthy evidence. He also used Wood's miniature arc in vacuum, and a variety of vacuum spark arrangements, but none of these sources appeared to yield lines in the most refrangible region.

VI. *Description of Arcs Used in the Present Investigation.*

The work done in the present investigation has been confined entirely to arcs of carbon, mercury, iron, copper, and zinc. It was found that an arc of a metal having a high fusion point may be maintained in a vacuum if some means is employed to start it by bringing the electrodes together and then separating them. The carbon arc was found to be the easiest to maintain and also to give the strongest radiations of very short wave-lengths, so that its spectrum has been carried the farthest into the unknown region.

The first lamp used was merely a circular glass bulb about 6 inches in diameter, attached to a brass tube with Kotinsky cement. The brass tube was attached to the slit of the spectroscope. The carbon electrodes were introduced through the glass tubes in the sides of the bulb, one facing directly towards the slit and the other at right angles to the first. A piece of rubber tubing over the electrode and glass tubing rendered the joint air-tight, and still allowed enough freedom to make and break the arc. This lamp was not a success, because the intense heat destroyed the glass. Also, since the evacuation of the lamp took place through the slit, particles from the vapours became deposited on the sides of the latter and tended to obstruct the passage of the light. This latter difficulty was overcome by attaching permanently over the slit a short brass tube to which the lamp could be fixed. From the side of this a pipe was led off through a small steam valve to the pump system.

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[*] Handke, 'Inaugural Dissertation,' Berlin, 1909.

[†] Lyman, 'Science,' vol. 45, p. 187 (February 23, 1917).

The first successful lamp was made in the form of a brass cylinder about 10 cm. long and 10 cm. in diameter. A brass tube (" A," fig. 6), 3 cm. in diameter, soldered into the centre of one end, connected this chamber to the tube fastened to the slit. The two tubes were of such sizes that they just telescoped, and a piece of pure gum rubber tubing was placed over the joint. A small brass tube, " B," was soldered in the centre of the opposite end, and through it the positive electrode was introduced. This arrangement assured, that no matter how the electrodes might be moved, the hot positive electrode always was directly opposite the slit. A similar tube, " C," fixed in the side of the lamp at a right angle with the first, served to admit the negative terminal. The positive terminal was insulated from the case by a sleeve of glass or quartz, and the negative terminal was earthed. Another tube, " D," 3 cm. in diameter, having a glass window in its end, allowed the operator to observe the arc. As before, the openings through which the electrodes were introduced were made air-tight by the use of a short piece of rubber tubing (fig. 7). Finally, the lamp thus formed was enclosed in a tin water jacket, the various tubes being allowed to project through as shown in fig. 6. Water was kept circulating about the lamp while in operation, entering through the tube " E " and escaping through " F." This lamp was used to obtain the spectrum of carbon, iron, and copper.

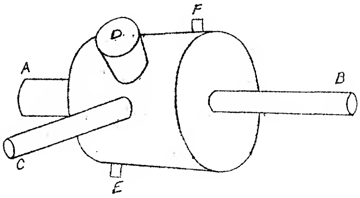

Fig. 6.

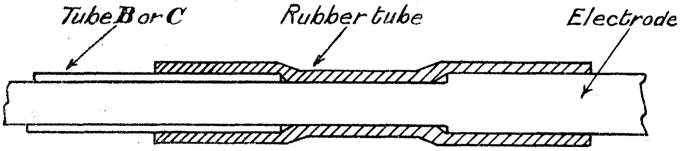

Fig. 7.

The lamp used to obtain the mercury arc is shown in fig. 8. It was made of glass tubing about an inch and a quarter in diameter. The arms " A " and " B " were each about a foot long, and " C " was 6 inches long. " C " was attached to the tube of the spectroscope with a piece of rubber tubing, and, when in place, a vertical plane section through the lamp is shown in fig. 9. The end of the tube " A " was closed by a metal plug sealed in with wax, and through this plug an iron wire was passed, which served to carry the brass ring electrode "D."

"B" was closed by a ground joint through which two copper leads were inserted. The ends of these leads, close to the electrode "D," were joined by a short piece of 15 mil. tungsten wire. The receptacle "E" (fig. 9) was filled with mercury, which was gently heated with a Bunsen flame. One lead to the filament was earthed, and the ring was raised to any desired potential above the filament. A current of 15 ampères through the filament served to heat it a glowing white. The striking of the arc and its intensity appeared to depend on three things: the temperature of the filament which supplied the electrons, the density of the mercury vapour bombarded by these electrons, and the voltage between the ring and the filament. Since, when the mercury vapour was made very dense a great deal was deposited about the tubes of the lamp and threatened even to enter the spectrograph, very little heat was applied to the mercury after the lamp was once started. This resulted in an arc which was not very intense, and which failed to persist at all below 30 volts. However, there appeared to be some compensation with a weak arc, for the cloud of vapour through which the radiation had to pass on its way through the tube "C" was then not so dense, and less absorption appeared to result. A long exposure with a weak arc brought out the line $\lambda = 1435$ Å.U., but this line did not appear when a much brighter arc was used.

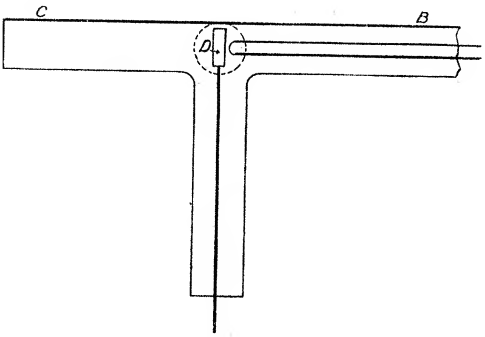

Fig. 8.

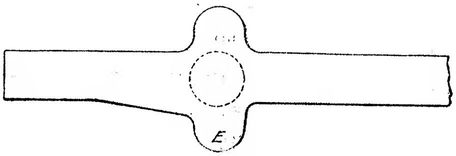

Fig. 9.

When iron and also copper electrodes were used with the lamp shown in fig. 6, the arc proved very difficult to manage because a potential difference of about 150 volts was required in order to make it strike. When once it struck, however, the resistance fell almost to zero, and the intense heat fused the electrodes, either causing them to unite or to drop off. So far no method has been devised to overcome this defect. As a spark was always made between the terminals at a lower voltage when they separated, a motor was attached to one terminal, to give it a slight vibratory motion, and so make and break the contact rapidly and keep up a continual sparking. It was found, however, that this did not yield any lines whatever in the region below $\lambda = 2000$ Å.U. It appears, therefore, that the metal must be incandescent to yield a radiation rich in the very short wave-lengths.

The most perfect results by far were obtained with a carbon arc in a vacuum. The lamp used was also that shown in fig. 6. Short pieces of carbon were turned to the size of a lead pencil and inserted in iron receptacles on the ends of the electrodes. While the potential difference applied here was only 110 volts, it was found that, with a suitable variable resistance in series, the arc was just as bright as the iron one, but it did not radiate such intense heat. The arc had to be attended closely, for, as the carbon burned away, a slight difference in the distance between the terminals destroyed it. With 220 volts applied a much brighter and more persistent arc was obtained, but it burned the terminals so rapidly that it was abandoned and the lower voltage was used.

VII. *Results.*

The various plates obtained in the present investigation were carefully measured up, and the wave-lengths obtained with the different arcs are given in Table I.

The spectrum of mercury, it will be observed, has been measured to $\lambda = 1435$ Å.U., that of iron to $\lambda = 1427$ Å.U., and that of copper to $\lambda = 1925$ Å.U. In the case of carbon the shortest wave-length observed was at $\lambda = 584$ Å.U. It was very difficult to get good plates for printing, and a number of the faint lines do not appear in the reproductions. Plate 3 will serve to illustrate the results obtained with the mercury and carbon arcs. The plates for copper and iron were not suitable for printing, although the lines were clearly visible on them.

(a) *Mercury.*—A comparison of our results, obtained with the mercury arc, compared with those obtained by Lyman and Wolff, shows that a number of wave-lengths observed by these investigations did not come out on our plates. Among those which did not appear are $\lambda = 1832{\cdot}6$ Å.U., $\lambda = 1774{\cdot}9$ Å.U., and $\lambda = 1402{\cdot}5$ Å.U., observed by both Lyman and Wolff, $\lambda = 1810$ Å.U and $\lambda = 1518{\cdot}6$ Å.U., observed by Lyman, and also the pair at $\lambda = 1672{\cdot}76$ Å.U. and $\lambda = 1675{\cdot}55$ Å.U., observed by Wolff.

(b) *Copper.*—The results obtained with the copper, it will be noticed, were rather meagre, and no wave-lengths were observed shorter than $\lambda = 1925$ Å.U.

(c) *Iron.*—The lines given in Table I for iron were obtained on a single plate with the use of the water-cooled lamp shown in fig. 6. While wave-

Table I.—Table of Wave-lengths.

Mercury.	Intensity.	Copper.	Iron.	Carbon.	Intensity.
λ = 2054 Å.U.	3	λ = 2243 Å.U.	λ = 2027 Å.U.	λ = 2023 Å.U.	5
2029	2	2227	1994	2020	1
1990	1	2218	1975	1955	1
1974	2	2179	1954	1933	25
1943	50	2160	1944	1813	1
1874	2	2123	1935	1767	1
1849	100	2120	1924	1759	1
1649	5	2085	1905	1667	25
1435	1	2070	1885	1578	1
		2040	1863	1574	25
		2000	1835	1497	1
		1980	1815	1477	2
		1925	1799	1447	2
			1783	1416	1
			1738	1353	Doublet 30
			1728	1348	25
			1666	1343	2
			1620	1328	2
			1593	1299	3
			1574	1297	5
			1529	1281	4
			1520	1200	1
			1485	1064	2
			1470	1039	1
			1453	1004	3
			1443	934	2
			1427	918	1
				584	1

lengths as short as λ = 1427 Å.U. were obtained, it is just possible that some of them belonged to the secondary gas spectrum, as it was always noted that considerable gas was given off by the electrodes when the arc was struck.

A number of wave-lengths, which agree fairly well with wave-lengths quoted by Lyman as gas lines in the hydrogen and carbon monoxide spectra, are given in Table II. The present work, however, will have to be repeated and extended before a definite decision can be reached regarding the origin of these lines.

(d) *Carbon.*—The carbon spectrum in the Schumann region contains a number of very strong lines such as λ = 1933 Å.U., λ = 1667 Å.U., λ = 1353 Å.U. (double), and λ = 1348 Å.U. Among these, and rather evenly distributed, a large number of faint lines appeared. The exposures given averaged about three hours each. With longer exposures doubtless new faint lines would have appeared. When photographing the region about 500 Å.U., it was found that the short wave-length end of the plates became fogged. This was thought to be due to the approach of the large central slit image which means, if this supposition be correct, that the limit of the possibilities of the grating was almost reached. It was found that the

Table II.

Wave-lengths observed by the Authors with iron arcs.	Wave-lengths of gas lines given by Lyman.*		Gas.
λ = Å.U.	λ = Å.U.	Intensity.	
1427	1427·8	7	Hydrogen.
	1426·8	3	,,
1443	1443·6	7	,,
1453	1452·0	3	,,
1470	1468·6	6	,,
1485	1486·9	9	,,
1520	1519·0	6	,,
	1520·0	5	,,
1574	1571·7	7	,,
	1574·3	5	,,
	1577·2	8	,,
1593	1593·6	7	,,
1620	1619·9	2	,,
	1621·1	7	,,
	1622·1	3	,,
1728	1729·5	—	Carbon monoxide.
1783	1785·1	—	,, ,,
2027	2026·5	—	,, ,,

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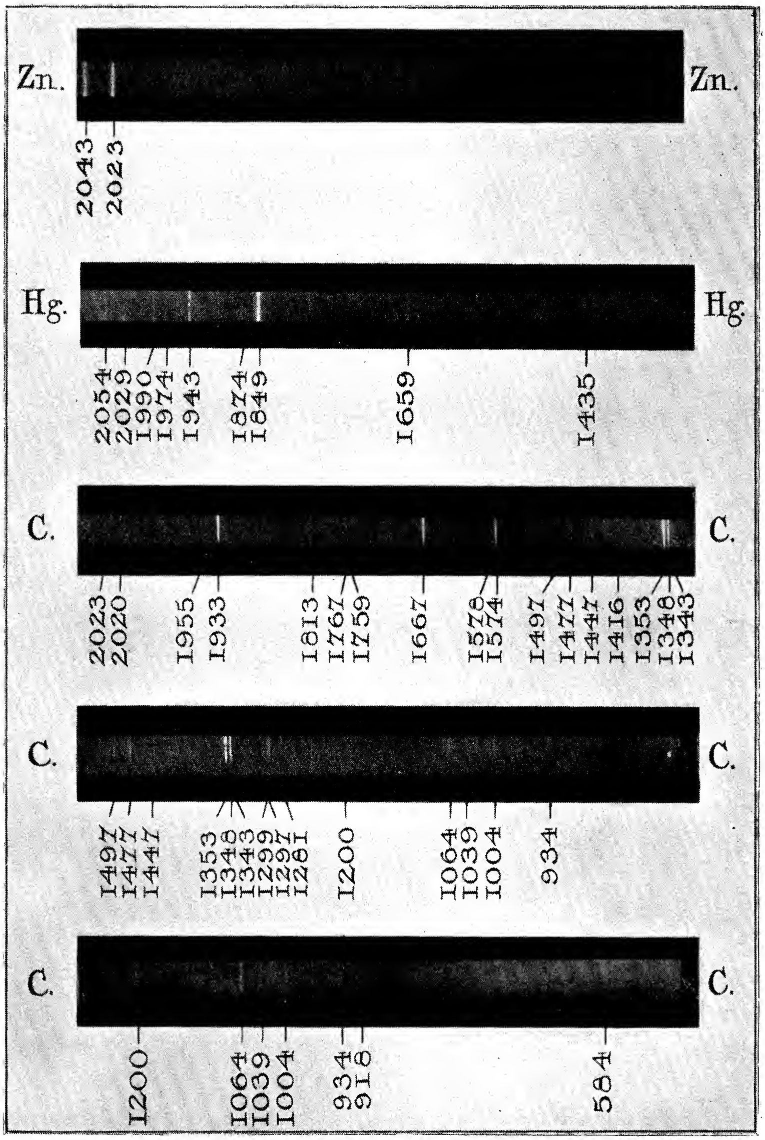
* Lyman, "The Spectroscopy of the Extreme Ultra-violet."

spectrograph had to be washed out with hydrogen before each exposure in order to secure success. The hydrogen appeared to displace the oxygen in the pores of the metal and thus almost all of the oxygen was probably eliminated early in the experiment. Without the use of hydrogen no results were obtained below λ = 1200 Å.U.

Table III.—Carbon Vacuum Arc Spectrum.

McLennan and Lang.	Intensity.	McLennan, Ainslie, and Fuller.	Insensity.
λ (Å.U.).		λ (Å.U.).	
2022	5		
2020	1		
1955	1	1953·5	2
1933	25	1930·5	15
1813	1	1811·7	4
1767	1		
1759	1	1758·1	9
1667	25	1656·9	10
1578·	1	1577·6	3
1574	25	1562·0 1561·2 1560·5	9 9 9
1497	1		
1477	2	1482·8	5
1447	2		
1416	1		

McLennan and Lang. *Roy. Soc. Proc., A, vol.* 95, *Pl* 3.



In a recent investigation by McLennan, Ainslie, and Fuller of the carbon vacuum arc Schumann spectrum, studied with a fluorite spectrograph, many wave-lengths were observed which did not come out on our plates. Only a few wave-lengths were common to the two investigations, and these are given in Table III. The agreement in the measurements, it will be seen, is only fair.

Too much reliance must not be placed on the results obtained in the present investigation, for no special effort was made to obtain absolutely pure metals for use in the arcs, and time was not available for refining the work. The best that can be said is that the same lines always appeared for different samples of the metal used.

On the Absorption Spectra and the Ionisation Potentials of Calcium, Strontium, and Barium.

By J. C. McLennan, F.R.S., and J. F. T. Young, M.A., University of Toronto.

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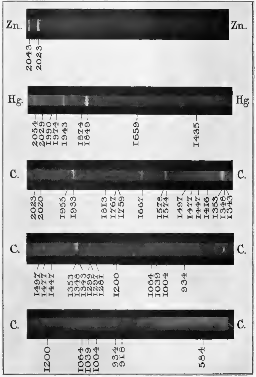
[Plates 4–6.]

I. *Introduction.*

In view of the probability that the ionisation potential of an element is connected by the quantum relation $\nu = (1{\cdot}5, \mathrm{S} \times h)/e$ with the characteristic spectral frequency $\nu = (1{\cdot}5, \mathrm{S})$, it has become desirable to determine the value of this frequency for as many of the elements as possible. Its value, moreover, is best found by identifying the members of the series $\nu = (1{\cdot}5, \mathrm{S}) - (m, \mathrm{P})$ in a spectrum and then calculating the limiting frequency of the series. Dunz, in his Inaugural Dissertation, gives the wave-lengths of several members of the series $\nu = (1{\cdot}5, \mathrm{S}) - (m, \mathrm{P})$ for each of the elements mercury, zinc, and cadmium; and Lorenser, in his Inaugural Dissertation, gives the wave-lengths of a number of the members of the same series for magnesium, calcium, and strontium. Lorenser, however, while giving $\nu = 5535{\cdot}69$ Å.U. as the wave-length of the first member of the series $\nu = (1{\cdot}5, \mathrm{S}) - (m, \mathrm{P})$, for barium, states that the remaining members of the series are not known.

Starting at this point, we recently investigated the spectrum of barium,


Zn.
2043
2023
Zn.
Hg.
2054
2029
1990
1974
1943
1874
1849
1659
1435
Hg.
C.
2023
2020
1955
1933
1813
1767
1759
1667
1576
1574
1497
1477
1447
1416
1353
1346
1343
C.
C.
1497
1477
1447
1353
1346
1343
1299
1297
1281
1200
1064
1039
1004
934
C.
C.
1200
1064
1039
1004
934
918
584
C.